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FINAL REPORT ON A STATISTICAL ANALYSIS OF ANTARCTIC SEA ICE

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Table of Contents

I. Introduction

II. Summary of Principal Results

III. Directions for Further Research

Appendix A: Statistical Methodology

Appendix B: "Spatial Cross-Correlation of Antarctic Sea Ice and Seabed Topography,"

by Richard D. De Veaux and Michael J. Phelan.

I. Introduction

We report briefly on our statistical analysis of Antarctic sea ice. Recall that our objectives are to examine the influence of seabed topography on sea-ice behavior and to identify persistent features in the ice field. In each case, the problem is one of extracting the relevant information from a time series of satellite images. Our approach combines the use of statistical image-processing filters and animation. In meeting our objectives, this protocol for analyzing a time series of images proves to be our most powerful data-analytic tool.

The idea behind our approach is this. We design a filter to localize patterns of sea-ice concentration within the sea ice field. An encavement in the area of Maud Rise is an example of a localized pattern. We apply the filter to each ice image in our data base, yielding a new time series of filtered images. Summary statistics from the filtered images create time series that quantify the relationship between topography and sea-ice concentrations. We then animate both the time series of filtered images and the derived statistics. The animation shows the temporal evolution of the highlighted pattern. This includes for example any movements, persistence, and seasonal recurrence of the pattern. We find that the animations uncover areas of the ice and period of time requiring closer examination.

II. Summary of principal Results

At present, we have completed an analysis of the data of 1983. Our principal finding is that variations in sea-ice concentration correlate systematically with those in seabed topography. In specific, the percentage of ice varies proportionally with the depth of the sea floor below. This influence extends throughout the year and over the entire region, including patterns of growth and dissipation at the edges and in the interior.

We find that the correlation described above admits the following refinement. That is, our results clearly indicate that most of the variation in sea-ice concentration is accounted for by gradients in seabed topology. This result is significant both in terms of its statistical strength and in terms of its scientific merit. Regarding the latter, it is consistent with the notion that ocean currents, such as deep-ocean upwelling, are responsible for encavements in sea-ice concentration, in as much as these are directed by gradients in seabed topography.

We thus find that the presence of orographic features in the sea bottom appears to determine the placement, shape, and spatial extent of persistent features in the ice field. The most salient examples occur about Maud Rise, Ross Sea, and Antarctic-Pacific Ridge, where the presence of mountains and ridges induces well delineated regions of low sea-ice concentration. These apparent weakenings or encavements in the ice persist throughout the Austral Winter and locate interior regions of rapid dissipation during the Austral Spring. A similar, but for 1983 less dramatic, example is found in the region of the Cosmonaut Sea.

Any of the examples above will illustrate the marked influence of seabed gradients on sea-ice concentration in the interior of the sea ice. Our results show that this influence extends to the edge of the ice as well. Topography appears to determine the ultimate shape of the ice field through its effect on the extent of the northerly growth around the edge of the ice.

III. Directions for Further Research

Our focus in future research will remain on the role of seabed topography in sea-ice formation processes. Nevertheless, we will broaden our investigation to a study of the role of ocean currents and climatic winds. In this way, our future analyses of sea-ice formation will be coupled to scientific objectives in oceanography and to climatological studies of the Antarctic environment. Throughout our efforts, we plan to continue our emphasis on quantification and extraction of information from a time series of satellite images.

An outline of our specific research objectives is as follows:

1. extend our correlation analysis of the data of 1983 to the remaining years. Now that we have the basic protocol set, we expect to use supercomputer computing facilities to handle the large volume of data;

2. isolate several regions of the ice field highlighted in our correlation analysis. In this way, we extract a multivariate time series summarizing the patterns of correlation observed among these regions. Here we perform a frequency-domain analysis of these tieme series in the manner of Zeger (1985), who analyses time series of ozone measurements for trends and regional variability.

3. investigate the connection between topography, upwellings, vertical heat flux and encavements in sea-ice concentration (see for example Gordon and Huber (1990));

4. investigate the connection between ambients winds and sea-ice formation processes using climatic wind data;

5. further quantify the effect of topography on the growth of the ice at the edges.

Appendix A: Statistical Methodology

We outline our application of the protocol to each of our objectives.

A) The Five-Year Animation. We presently have five years of data spanning the years 1981 to 1985. There are about 180 images per year. Each represents a three-day average of brightness temperatures as observed from the Nimbus 7 SMMR satellite. The spatial resolution is about 30 km, so the images comprise 293 times 293 or 85,849 pixels each. We convert the brightness temperatures to sea-ice concentrations (using the algorithm suggested in Comiso and Zwally (1988)).

The original data contain missing values. These arise as the satellite makes incomplete aerial scans. We estimate the missing values by interpolation. Briefly, we combine the use of running medians of three in time and where necessary local spatial averages. In addition to estimating missing values, the running medians help attenuate the effects of synoptic-scale weather events.

The interpolations yield a set of clean images. We animate these in a five-year animation of sea-ice concentrations. It provides the first opportunity to witness the behavior of the sea ice through five seasons of formation and dissipation.

B) Seabed Topography. We aim broadly to examine the influence of seabed topography on sea-ice behavior. Here we focus on the patern of intercorrelation between sea-ice concentration and ocean depth. Measurements of the latter about Antarctica were made available to us by A.Gordon of Columbia University. We use these to create an image of the seabed topography at the spatial resolution of the ice images. We thus have a pair of images, one of sea ice and one of ocean depth, for every time in the five-year series. We explore these for the pattern of intercorrelation between the two.

The problem is to determine these correlations. Here we design two statistical image-processing filters for this purpose. The first of these determines the degree of local correlation between sea-ice concentration and ocean depth. It selects for regions where these measures are in strong linear dependence. The second filter determines the degree of correlation between local gradients in the surface of the sea bed and those gradients of the sea ice. It selects for regions where the rate of change in sea-ice concentration is proportional to that in ocean depth.

We implement these filters on the time series of ice images. This yields two new time series of correlation images, each depicting the desired pattern of association. Note well that these images depict local spatial correlations. Thus, the value at any pixel denotes the correlation among the pairs of measurements inside of a region centered there. These regions are about 330 km square. We animate the correlationimages. The animations highlight regions of the ice field and periods of its life cycle of particularly high association. And they show the temporal evolution of these patterns.

C) Feature Identification. Here we aim to identify persistent features in the ice field. We face the immediate challenge of defining what is meant by a feature. In general terms, we take a feature to be a regular pattern in the concentration of ice in the ice field. A convex region of low concentration embedded in a region of higher concentration is an example of such a pattern. To detect features in the ice the correlation filters described above select for features such as the encavements located near Maud Rise, Ross Sea, and the Antarctic-Pacific Ridge. We plan to compare these results with results obtained with more classical edge-detectors such as those treated in Lee, Lee, and Fam (1986).